Light hadron spectroscopy via charmonium decays

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Main questions

- Why so many states are seen in meson spectrum?
- Why so few states are seen in baryon spectrum?
- Does any of non-$q\bar{q}$ or non-qqq states, predicted by QCD, really exist?
- What are effective degrees of freedom to describe internal structure of hadrons, and how do they interact?

Light hadron spectroscopy in charmonium decays

- Large production cross-section = Enormous statistic & good background conditions
- Any quantum number is accessible in J/Ψ and Ψ' decays
- Initial state is well defined (1^{-} with almost zero longitudinal component)
- High probability of radiative decays, providing access to all C=+1 state, while C=-1 state is forbidden
- 3-gluon annihilation process is flavor-blind, and it is a nice source of excited strange and charmed baryons for baryon spectroscopy

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Rich source of charmonium and a good detector are needed

Light meson spectrum

- Constituent quark model provides generally good description of meson spectrum, but…
  - Too many 0^{++} states: σ, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $f_0(1810)$
  - The same for isoscalar 1^{++} states: $f_1(1285)$, $f_1(1420)$, $f_1(1510)$ observed instead of 2 predicted
  - Origin of $a_0(980)$ and $f_0(980)$?
- But, NO clear evidence of non-$q\bar{q}$ meson state is found so far

Looking for new phenomena: glueballs

- Radiative decays of J/ψ are gluon-rich, and it is an ideal place to look for lightest (0^{++}, 2^{++}) glueballs (predicted by LQCD)
- Glueballs with "normal" quantum numbers must mix with "normal" $q\bar{q}$-meson
- Precise measurement of coupling to different final states is necessary to prove glueball existence :
  - Systematic studies of $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $f_0(1810)$ in decays $J/\psi \to \gamma PP, \gamma VV$ and complementary hadronic decays
  - Study of $\eta(1295)$, $\eta(1405)$, $\eta(1475)$, $\eta(1760)$, $\eta(2225)$ in $J/\psi \to \gamma\eta\pi\pi$, $\gamma\eta'\pi\pi$, $\gamma K\bar{K}\pi$, etc.
  - Search for tensor glueball candidate $f_J(2220)$, in $J/\psi \to \gamma\eta\eta$ and $\gamma\eta\eta'$
  - ...

Looking for new phenomena: hybrids, multiquarks and molecules

- Hybrids: main signature is exotic quantum numbers (like 1-+,)
  - For example, search for $\pi_1(1400)$ in $J/\psi \to \rho\eta\pi^0$
- Multiquarks: expected to be broad states, if above the hadron threshold
  - Any enhancement in invariant mass near the threshold could be a signature of multiquarks
  - Precision study of $J/\psi \to \gamma\omega\varphi$, $J/\psi \to \gamma p\bar{p}$, $J/\psi \to pK^-\bar{\Lambda}$ may shed light on these states
- Molecular states
  - Study of possible $a_0(980)$ - $f_0(980)$ mixing in $J/\psi \to \phi f0(980) \to \phi a0(980) \to \phi\eta\pi^0$
  - $\Lambda(1405)$ as KN molecule?

The problem of σ and κ mesons

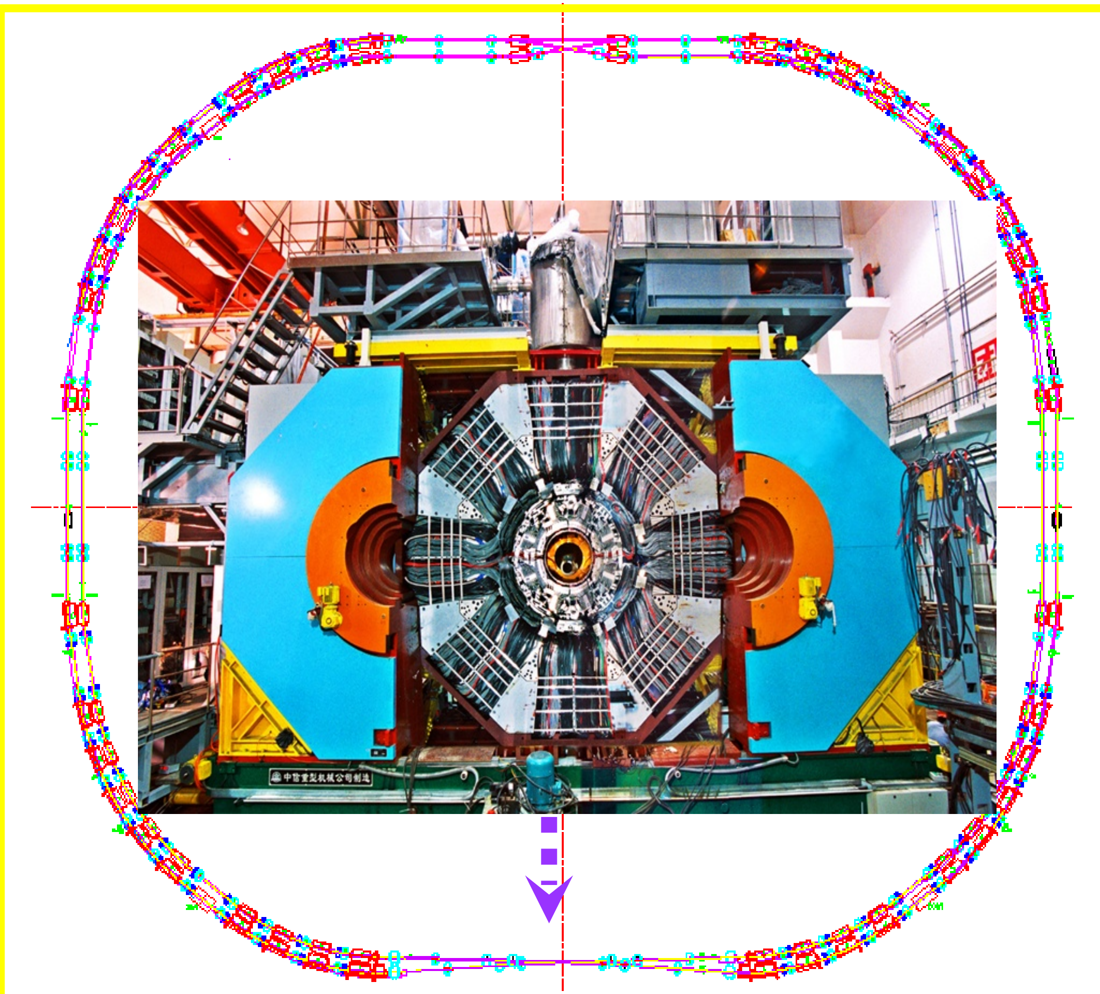
- Existence of σ and κ is proposed to describe ππ and Kπ and scattering data, respectively, however they do not fit into ordinary $q\bar{q}$ nonet
- Recent observations of σ:
  - CLEO found evidence of σ in $D^+ \to \pi^-\pi^+\pi^+$
  - BESII observed σ in $\psi(2S) \to \pi^+\pi^- J/\psi$ and $J/\psi \to \omega\pi^+\pi^-$
- Recent observations of κ:
  - FNAL E791 found evidence of neutral κ in $D^+ \to K^-\pi^+\pi^+$
  - FOCUS data on $D^+ \to K^-\pi^+\mu^+\nu$ require K^{*0} interfere with either a constant amplitude or a broad 0^+ resonance in Kπ
  - BESII observed neutral κ in $J/\psi \to K^{*0}K\pi \to K\pi K\pi$. Observation of charged κ in reported recently [arxiv:1002.0893].
- However, no indisputable proof of their existence is given so far
- More experimental studies are necessary, and looking into charmonium decays to states containing ππ and Kπ may be helpful.

Baryon spectroscopy

- **Constituent quark model explains spectrum of low-lying baryons, but fails to describe spectrum of excited baryons**
- **Advantages of baryon spectroscopy in charmonium decays**
  - **Isospin conservation ensures that the $J/\psi \to \bar{N}N\pi$ ($\bar{N}N\pi\pi$) decay processes produce pure isospin=1/2 πN ($\pi\pi N$) systems**
  - **Charmonium decay to baryons goes via virtual gluons – a nice environment to look for "missing" N* resonances**
  - **ψ' decays especially important, since they allow to study excited hyperons $\Lambda^*, \Sigma^*, \Xi^*$. Thus, for example, can access doubly strange Ξ^* baryons – more than 30 such states predicted, only 2 have been seen**

The BEPCII/BESIII project

China, Germany, Italy, Japan, JINR, Pakistan, Korea, Russia, USA



The project timeline

2003: BEPC/BES-II upgrade started

19 July 2008: First e+e- collision at BESIII

November 2008: Luminosity of 1.2 x10^{32} $cm^{-2}s^{-1}$ achieved

Spring 2009: 106M $\psi(2S)$ decays recorded (×4 CLEOc)

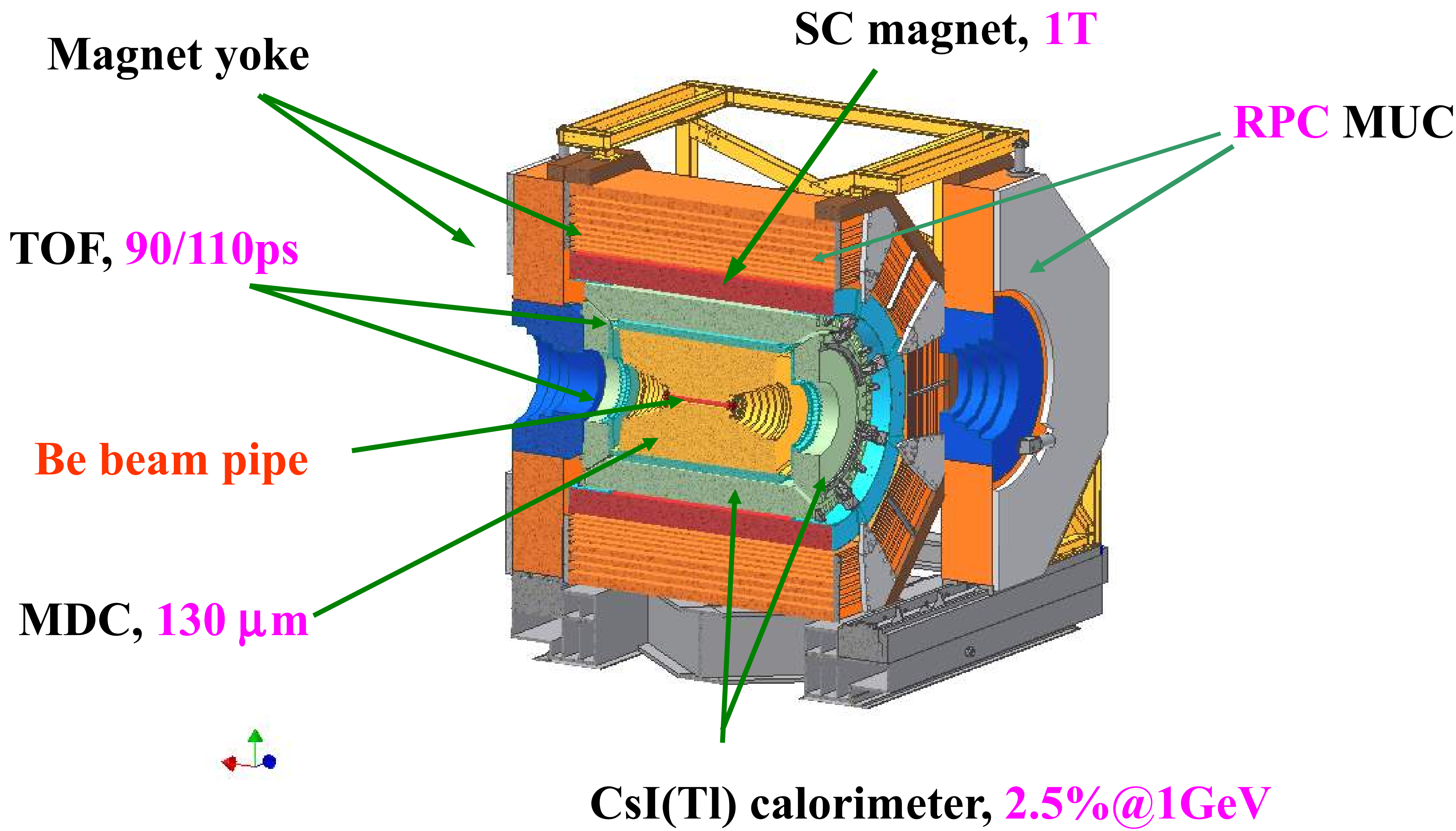
May 2009: Luminosity of 3.2 x10^{32} $cm^{-2}s^{-1}$ achieved

July 2009: 226M J/ψ decays recorded (×4 BESII)

14 January 2010 till now: Started take data of decays $\psi(3770) \rightarrow DD$. About 600 pb^{-1} (2/3 CLEOc) collected already.

The BES-III detector

Detailed description: NIM A 614(2010)345-399



Detector performance

Sub-system	Design		Achieved
MDC	σ_{xy} :	130 μm	135 μm
	δP/P:	0.6% @ 1GeV	0.5% @ 1GeV
	σ(dE/dx):	6-7 %	5.8%
EM Calorimeter	δE/E:	2.5% @ 1 GeV	2.3% @ 1 GeV
TOF detector	Barrel: single layer Barrel: double layer Endcap:	100 ps 80-90 ps 110 ps	100ps 78 ps 125 ps

First results of BES-III

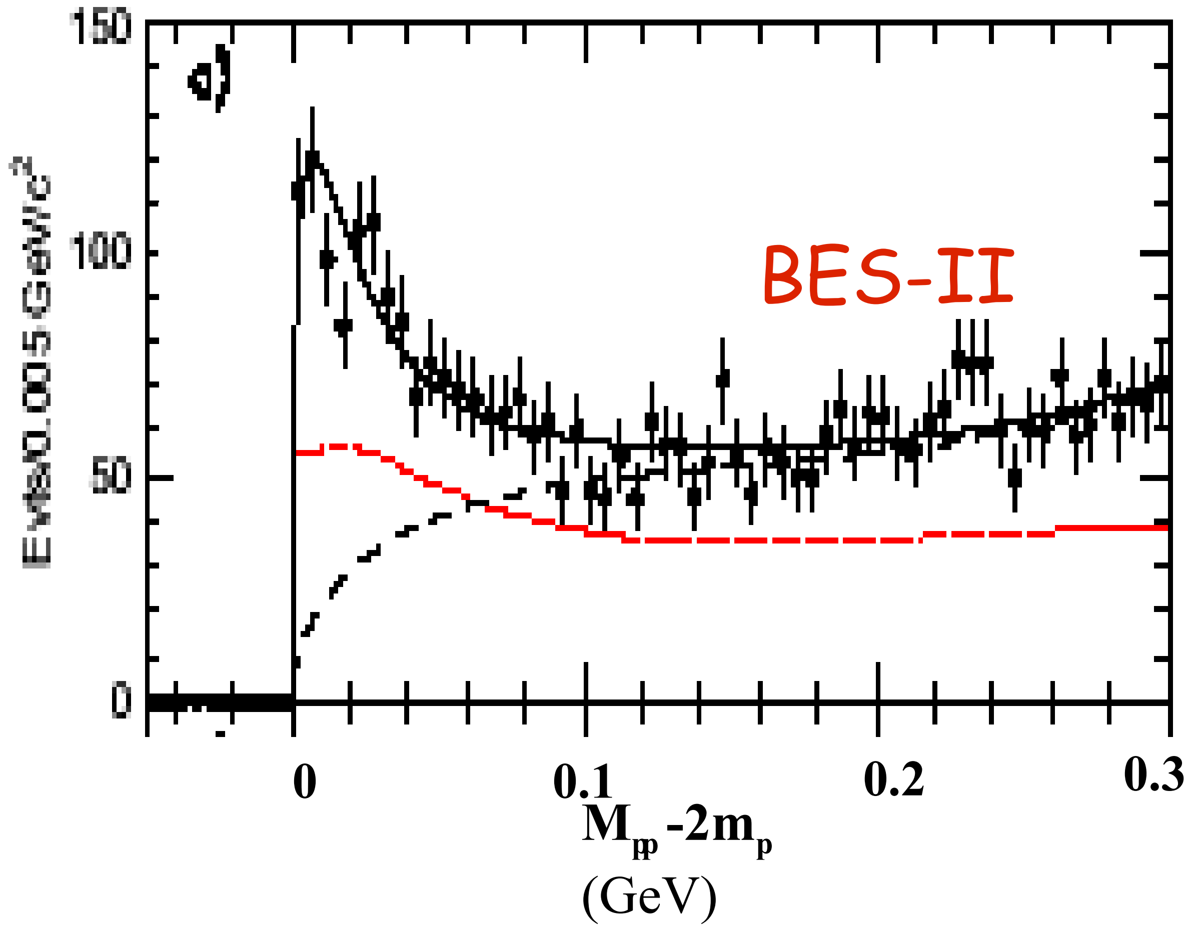
With ~110M of ψ' decays and ~220M J/ψ decays:

- $p\bar{p}$ threshold enhancement is confirmed in $J/\psi \to \gamma p\bar{p}$ decay
- $p\bar{p}$ threshold enhancement is NOT observed in $\psi' \to \gamma p\bar{p}$ decay
- X(1835) confirmed in $J/\psi \to \gamma\pi\pi\eta'$
- Branching fractions of χ_{C0}, $\chi_{C2} \to \pi^0\pi^0, \eta\eta$ measured (separate talk by Liu Chunlei)
- Properties of $h_c(^1P_1)$ measured in ψ' decay (separate talk by Wang LiangLiang)

$p\bar{p}$ mass threshold enhancement: beginning of a story

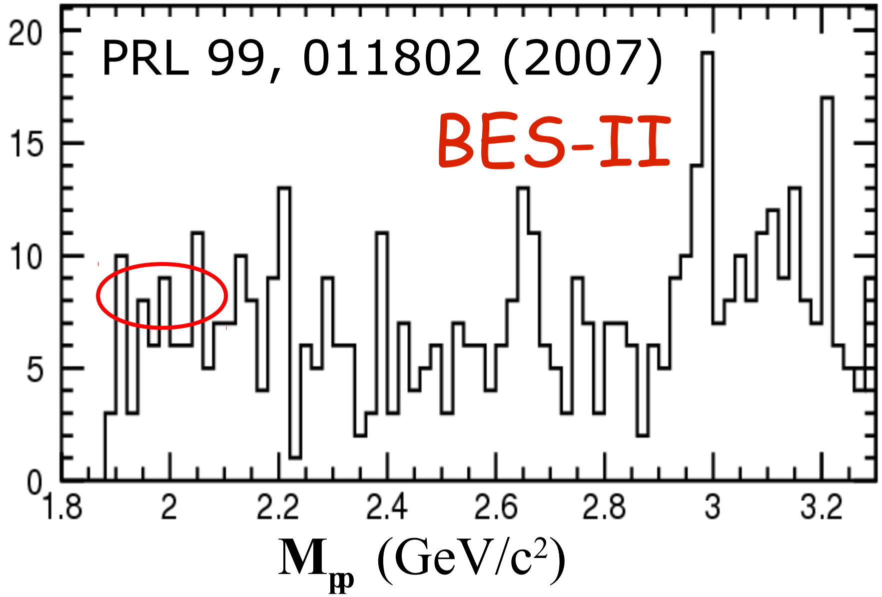
$$J/\psi \rightarrow \gamma p\bar{p}$$

PRL 91, 02201 (2003)



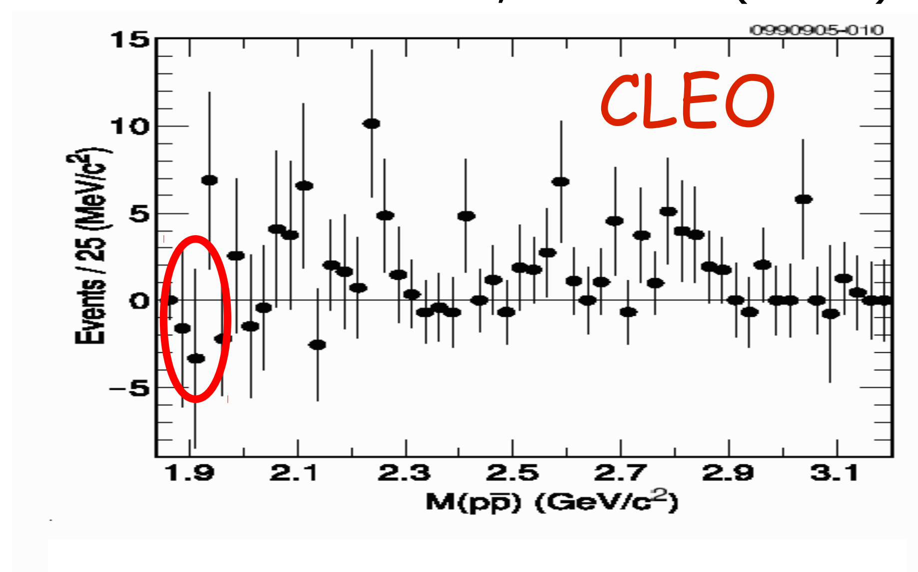
Several *non*-observations

$\psi' \to \gamma p\bar{p}$

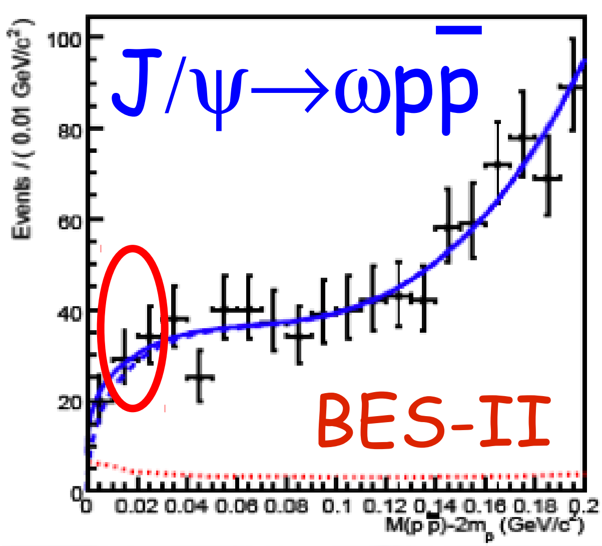


$\Upsilon(1S) \to \gamma p\bar{p}$

PR D73, 032001 (2006)



EPJ C53 ,15 (2008)

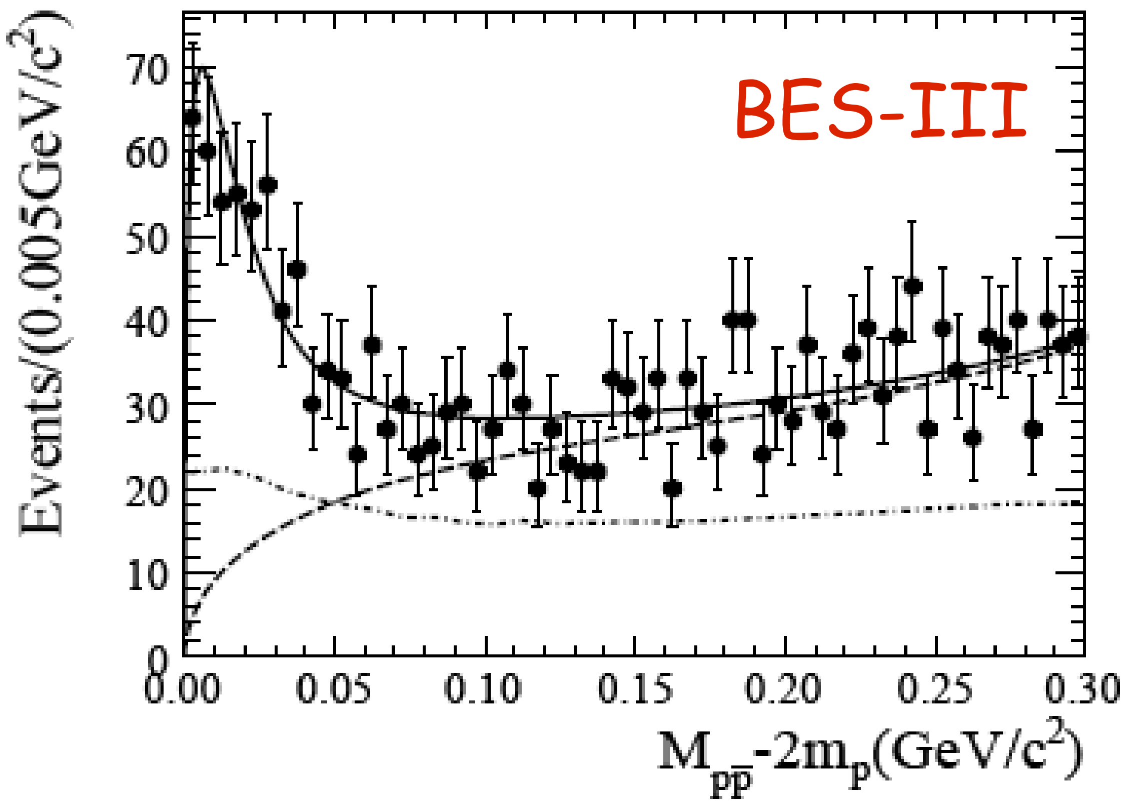


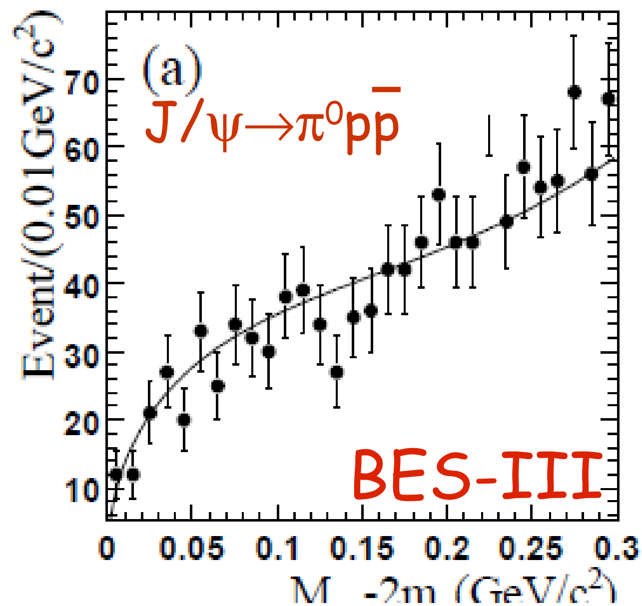
No significant narrow strong enhancement near threshold

Observation of an anomalous enhancement near the threshold in $p\bar{p}$ mass spectrum at BES-III

Chinese Phys C34(4): 421-426, 2010

$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$



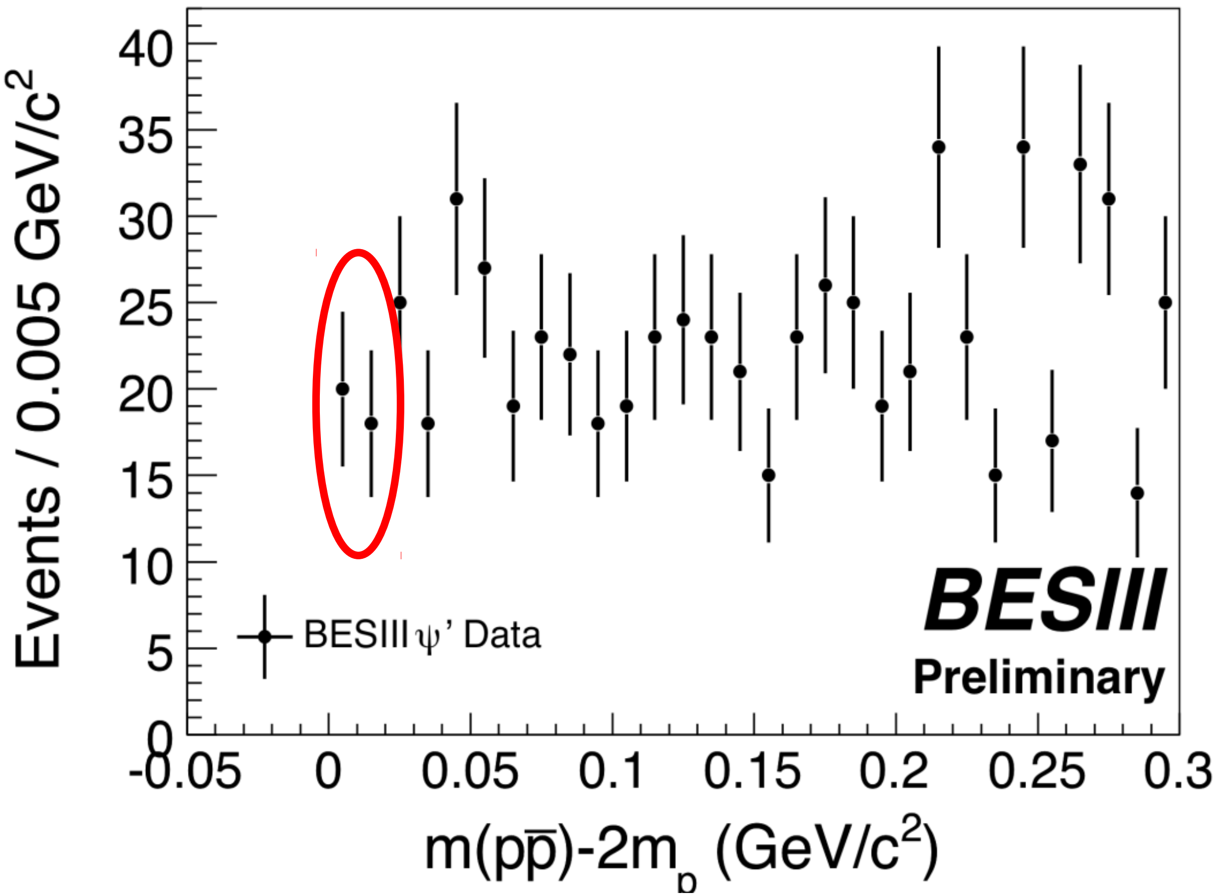


Not compatible with: η(1760), π(1800)

Fitted with a S-wave BW,
$M=1861^{+6}_{-13}$ (stat)$^{+7}_{-26}$ (syst) MeV/c²
$\Gamma < 38$ MeV/c² (90% CL)

This enhancement is NOT observed in Ψ' decay

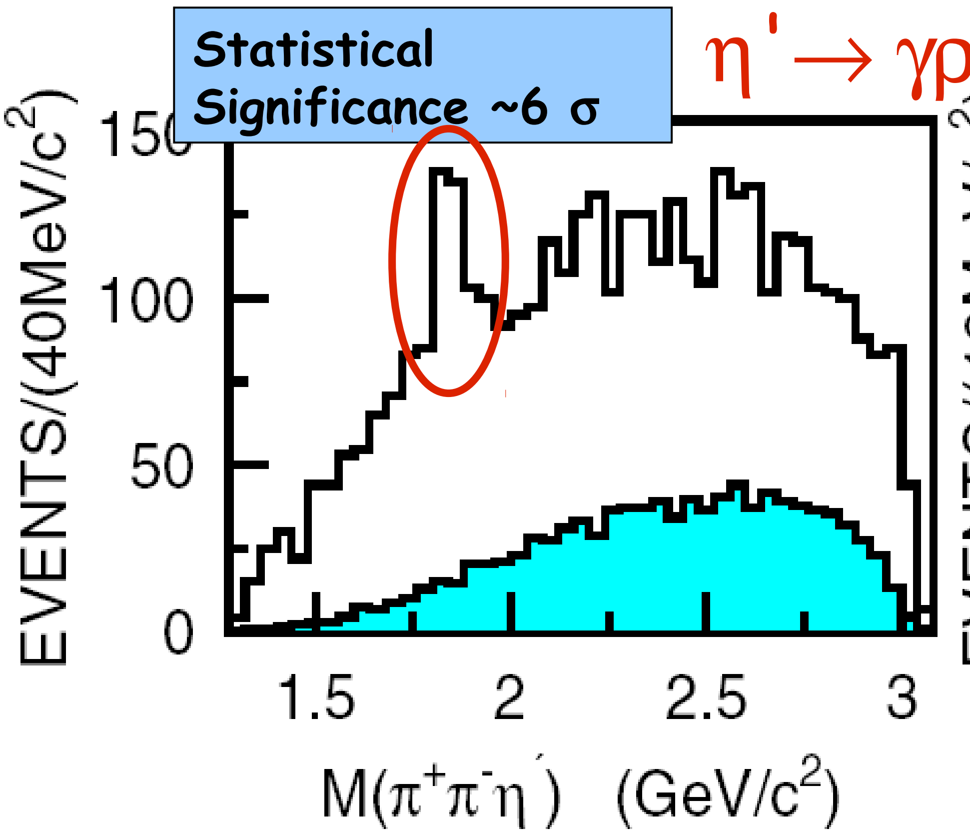
$\psi' \to \gamma p\bar{p}$

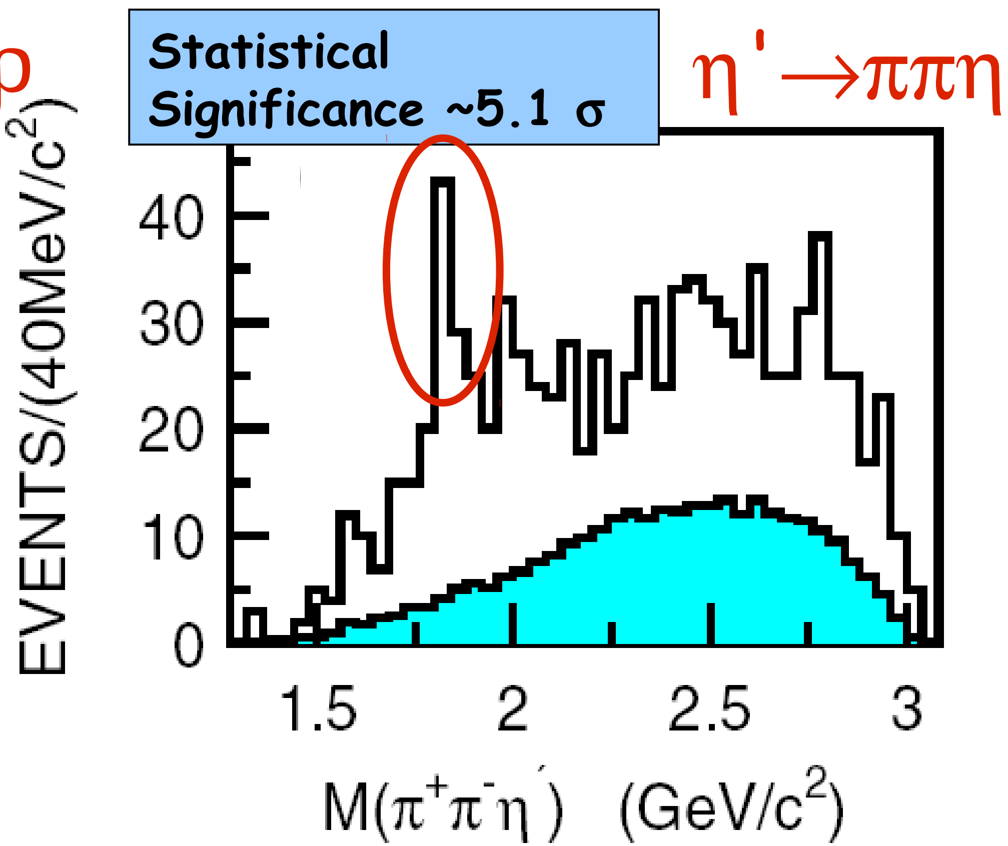


Observation of X(1835) $J/\psi \to \gamma\eta'\pi^+\pi^-$ at BESII

PRL 95,262001(2005)

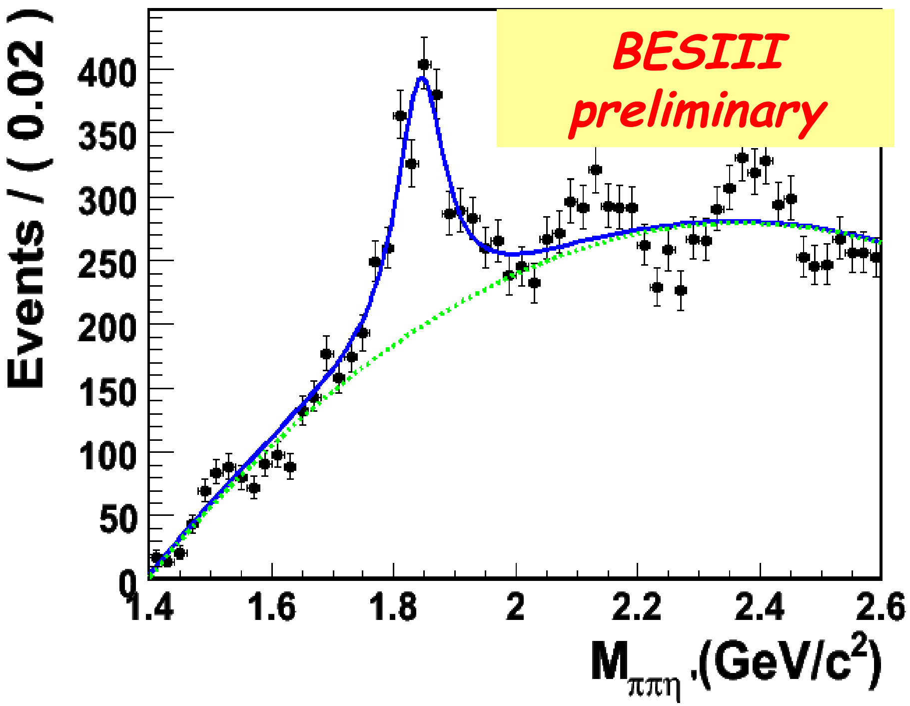
58M J/ψ



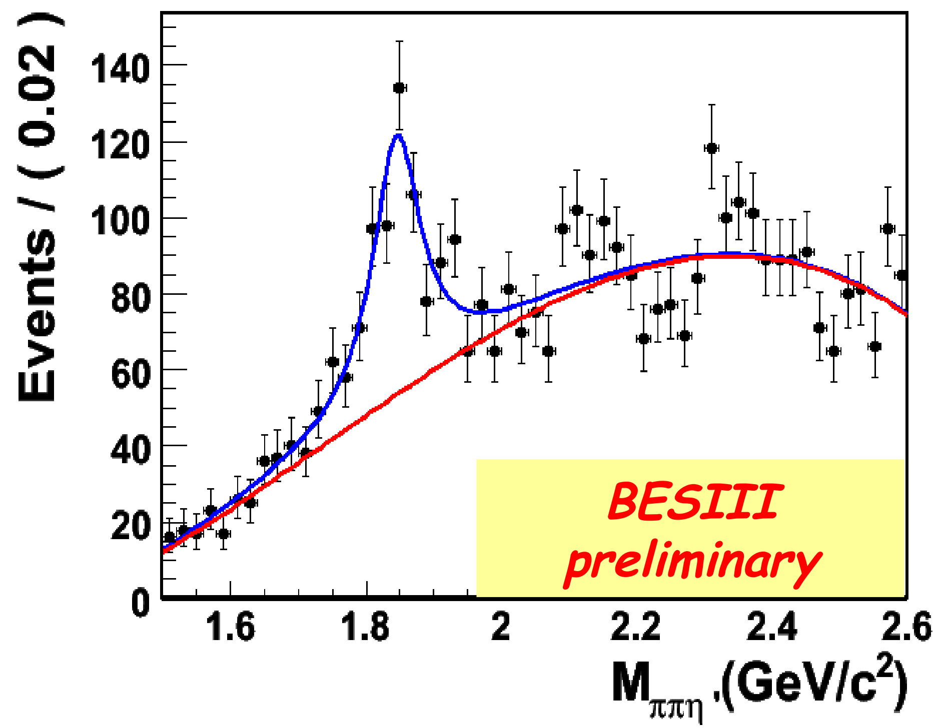


Mass spectrum of $\eta'\pi^+\pi^-$ in $J/\psi \to \gamma\eta'\pi^+\pi^-$

$\eta' \to \gamma\rho$



$\eta' \to \eta\pi^+\pi^-$

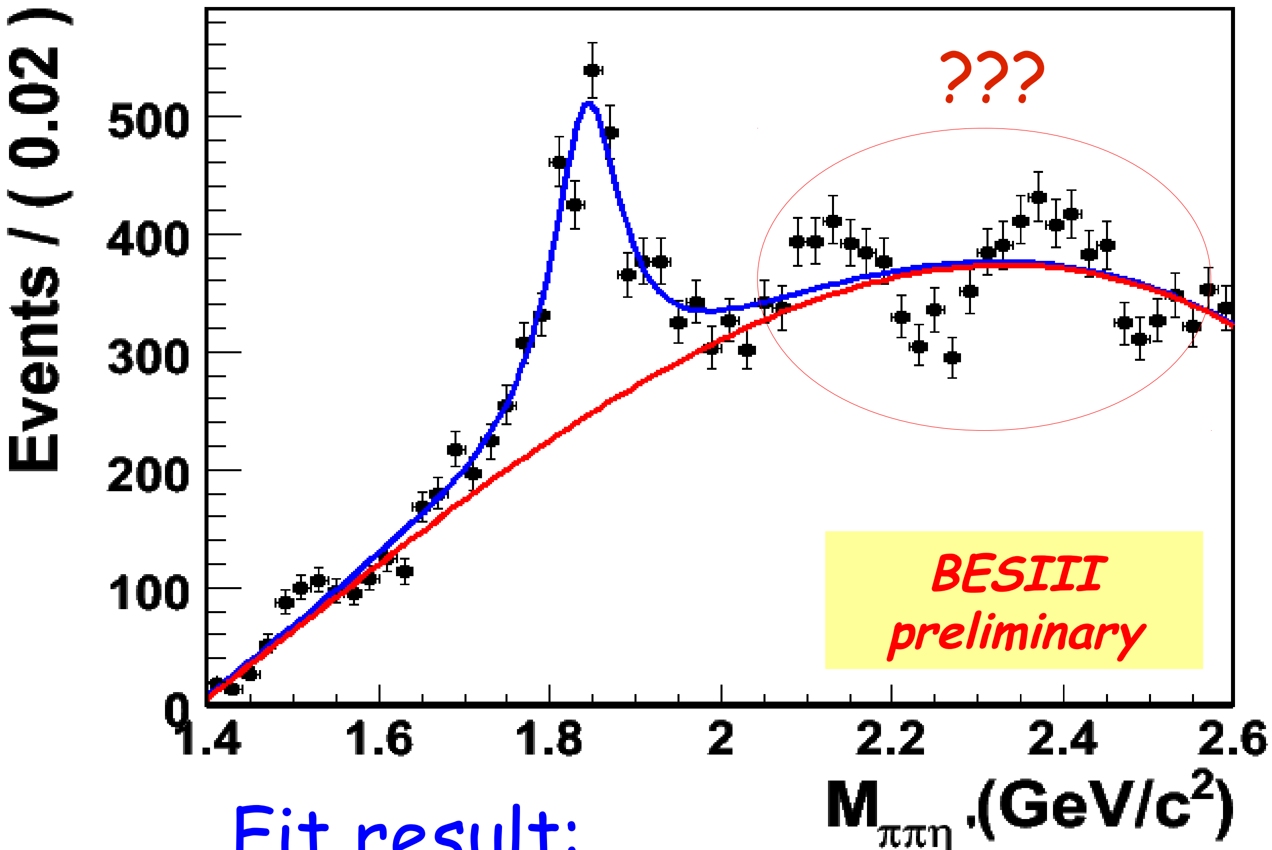


Significant peak at M~1835MeV

Statistic significance of X(1835) is about 18σ

Statistic significance of X(1835) is about 9σ

Combined mass spectrum of two decay modes



Fit result:

M = 1842.4 ± 2.8(stat) MeV

Γ= 99.2 ± 9.2(stat) MeV

Significance ~21 σ

Summary

- Charmonium decays provide an excellent lab for light hadron spectroscopy
- The BES-III experiment gives an opportunity for precision measurement of light hadron spectra, search for glueballs, study of excited baryons etc.
- First results are already obtained:
  - $p\bar{p}$ threshold enhancement is confirmed in $J/\psi \to \gamma p\bar{p}$ decay
  - $p\bar{p}$ threshold enhancement is NOT observed in $\psi' \to \gamma p\bar{p}$ decay
  - X(1835) confirmed in $J/\psi \to \gamma\pi\pi\eta'$